Supersymmetric Standard Models, Flux Compactification and Moduli Stabilization

Mirjam Cvetič and Tao Liu*

Department of Physics and Astronomy,
University of Pennsylvania,
Philadelphia, PA 19104-6396, USA

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Based on the T-dual constructions of supersymmetric intersecting D6-models on $Z_2 \times Z_2$ orientifolds, whose electroweak sector is parallel with the orientifold planes with $Sp(2f)_L \times Sp(2f)_R$ gauge symmetry (hep-th/0407178), we derive and classify Standard Model-like vacua with RR and NSNS fluxes, which stabilize toroidal complex structure moduli and the dilaton. We find consistent four-family ($f = 4$) and two-family ($f = 2$) models with one- and two-units of the quantized flux, respectively. Such models typically possess additional gauge group factors with negative beta functions and may lead, via gaugino condensation, to stabilization of toroidal Kähler moduli. These models have chiral exotics.

Introduction Constructions of explicit supersymmetric Standard Models with supergravity fluxes turned on is an outstanding technical problem in string theory. Supersymmetric semi-realistic constructions with intersecting D6-branes provide a beautiful, geometric framework to engineer Standard Models with three families. The first such supersymmetric models were based on $Z_2 \times Z_2$ orientifolds [1, 2] [Non-supersymmetric constructions were given in [3, 4, 5, 6] (see also [7] and for earlier work [8, 9]).] Turning on supergravity fluxes will introduce a supergravity potential, helping stabilize the compactification moduli fields by lifting continuous moduli space of the string vacua in the effective four-dimensional theory (see e.g. [10]). However, introducing the supergravity fluxes further restricts the constructions, since such fluxes modify the global conditions on the tadpole cancellations. The fluxes will typically generate a back reaction on the original geometry of the internal space, thus changing the nature of the internal space.

On the Type IIA side the supersymmetry conditions of flux compactifications are less understood. Nevertheless recent work [11, 12] revealed the existence of unique flux vacua for massive Type IIA string theory with SU(3) structure, whose geometry of the internal six-dimensional space is nearly-Kähler and four-dimensional space anti-deSitter. One such example is the $\frac{SU(2)^3}{SU(2)} \simeq S_3 \times S_3$ coset space that has three supersymmetric three-cycles that add up to zero in homology [12, 13]. Therefore the total charge of the D6-branes wrapping such cycles is zero and no introduction of orientifold planes on such spaces is needed. Moreover, since the three-cycles intersect pair-wise, the massless chiral matter appears at these intersections. This construction [12] therefore provides an explicit example of supersymmetric flux compactifications with intersecting D6-branes. Further progress has also been made in the constructions of N=1 supersymmetric Type IIA flux vacua with SU(2) structures [12], leading to examples with the internal space comformally Calabi-Yau. However, explicit constructions of models with intersecting probe D6-branes for such flux compact-

ifications is still awaiting further study.

On the Type IIB side the intersecting D6-brane constructions correspond to models with magnetized branes which have the role of intersecting angle being played by the magnetic fluxes on the branes. The dictionary for consistency and supersymmetry conditions between the two T-dual constructions is straightforward, see e.g., [14]. The supersymmetric Type IIB flux compactifications are also better understood. In particular, examples of supersymmetric fluxes and the internal space, which is conformally Calabi-Yau, are well known (see e.g. [15] and references therein). The prototype example is a self-dual combination of the NSNS H_3 and RR F_3 three-forms, corresponding to the primitive (2,1) form on Calabi-Yau space. Since the back-reaction of such flux configurations is mild, i.e. the internal space remains conformal to Calabi-Yau, these Type IIB flux compactifications are especially suitable for adding the probe magnetized D-branes in this background. However, the quantization conditions on fluxes and the modified tadpole conditions constrain the possible D-brane configurations severely. In Refs. [14, 16] techniques for consistent chiral flux compactifications on orbifolds were developed, however no explicit supersymmetric chiral Standard Model flux compactifications were obtained. Most recently in [17] an example of a one-family Standard Model with the supersymmetric (three units of quantized) flux was constructed. This construction also yields three- and two-family models with one- and two-units of the quantized flux, thus providing the first examples of semi-realistic Standard Model flux compactifications. The D-brane sector construction is T-dual to models of intersecting D6-branes on the $Z_2 \times Z_2$ orientifold with the $Sp(2)_L \times Sp(2)_R$ symmetry in the electroweak sector [18, 19]. [Without fluxes, the first models of that type were toroidal models with intersecting D6-branes [18] where the RR tadpoles were not explicitly cancelled. The $Z_2 \times Z_2$ orientifold construction in [19] cancelled the RR-tadpoles by introducing an additional stack of branes with unitary symmetry. However, the original additional stack had $U(1)$ gauge

symmetry, which introduced the discrete global anomaly [20], as pointed out in [21]. The anomaly is due to an odd-number of intersections of $U(1)$ branes with $Sp(2N)$ branes, thus resulting in an odd-number of chiral super-fields in the fundamental representation of $Sp(2N)$; the non-anomalous models can be easily constructed by introducing analogous $U(2)$ branes instead, as in the revised version of [19].]

The aim of this paper is to study the construction of supersymmetric Standard Models with fluxes turned on. We shall employ the specific $Z_2 \times Z_2$ orientifold constructions that are T-dual to intersecting D6-brane constructions whose electroweak sector arises from D6-branes originally residing on top of the orientifold planes. These constructions (without fluxes) were discussed in detail in [19]. The first class is based on one-family $U(4) \times Sp(2f)_L \times Sp(2f)_R$ gauge symmetry (in the observable sector), which yields the f-family Standard Model gauge symmetry (with additional $U(1)$'s) by employing the brane-splitting mechanism. [For $f = 4$ and $f = 3$ such constructions (without fluxes) yield [19] anomaly free models without chiral exotics.] The second class is based on constructions with $Sp(2)_L \times Sp(2)_R$ as the starting electroweak symmetry [17, 18, 19]. Within this framework we first present two classes of constructions with supersymmetric fluxes (three-units of quantized flux) which, however, suffer from the discrete global anomaly [20].

We further classify anomaly-free flux compactifications based on the brane constructions with $Sp(2f)_L \times Sp(2f)_R$ electroweak sector: we find three- and four-family models ($f = 3, 4$) with one-unit of quantized flux, as well as one- and two-family models ($f = 1, 2$) with two-units of quantized flux. [Note however, that for $f = 3$ the breaking pattern of $Sp(6)_L \times Sp(6)_R$ down to $Sp(2)_L \times Sp(2)_R$ breaks supersymmetry [19].] For all constructed models, the turned on fluxes will fix the toroidal complex structure moduli [24]. In addition, these models typically possess a "hidden sector" group factor with a negative beta function; if such a gauge factor is associated with D7-branes, the non-perturbative infrared dynamics on these D7-brane may lead to gaugino condensation and stabilization of a toroidal Kähler modulus. The additional toroidal Kähler moduli may be fixed due to the supersymmetry constraints. [Note that the open string moduli and the Kähler moduli can form combined flat directions, allowing for brane recombinations (see [2]). However, due to the flux back-reaction it is expected that the open string moduli become massive [14]; in this case the supersymmetry conditions fix Kähler moduli.]

Model The generators θ and ω for the orbifold group $Z_2 \times Z_2$, act on the complex coordinates of T^6 as $\theta : (z_1, z_2, z_3) \rightarrow (-z_1, -z_2, z_3)$ and $\omega : (z_1, z_2, z_3) \rightarrow (z_1, -z_2, -z_3)$ and the projection ΩR, where Ω is the world-sheet parity projection and R (acting on Type IIA as the holomorphic Z_2 involution): $(z_1, z_2, z_3) \rightarrow (-z_1, -z_2, -z_3)$. The actions of ΩR, $\Omega R\omega$, $\Omega\theta\omega$ and $\Omega R\theta$

introduce, on the Type IIB side (i.e. after T-dualizing the $\text{Re}(z_1)$, $\text{Re}(z_2)$, and $\text{Re}(z_3)$ toroidal directions), 64 $O3$-planes and 4 $O7_i$-planes, each of them sitting on Z_2 fixed points of the ith T^2 and wrapping the other two.

To compensate for the negative RR charges from these O-planes, we need to introduce D(3+2n)-branes in our models which are filling up $D = 4$ Minkowski space and wrapping 2n-cycles on the compact manifold. These D(3+2n)-branes can be magnetized (The detailed discussion for toroidal/orbifold compactifications with magnetized branes is given in [14].) Concretely, for one stack of N_a D-branes wrapped m_a^i times on the ith 2-torus T_i^2, we turn on n_a^i units of magnetic fluxes F_a for the $U(1)_a$ gauge factor (associated with the D-brane center of mass motion) on each T_i^2, such that

$$m_a^i \frac{1}{2\pi} \int_{\mathbf{T}_i^2} F_a^i = n_a^i. \tag{1}$$

Hence the topological information of this stack of D-branes is encoded in N_a-number of D-branes and the co-prime number pairs (n_a^i, m_a^i).

The chiral massless spectrum can be generated from the "intersection" of two stacks of D-branes a and b denoted by the intersection number

$$I_{ab} = \prod_{i=1}^{3} (n_a^i m_b^i - n_b^i m_a^i) \tag{2}$$

The point for the spectra is that they should be invariant under the full orientifold symmetry group. A detailed discussion of Type IIA has been given in [1, 2], which can be easily interpreted into type IIB (see Table I).

TABLE I: General spectrum on magnetized D-branes in type IIB $T^6/(Z_2 \times Z_2)$ orientifold. The representations in the table refer to $U(N_a/2)$, the resulting gauge symmetry due to $Z_2 \times Z_2$ orbifold projection. In our convention, positive intersection numbers implies left-hand chiral supermultiplets.

Sector	Representation
aa	$U(N_a/2)$ vector multiplet
	3 adjoint chiral multiplets
$ab + ba$	I_{ab} ($\square_a, \overline{\square}_b$) fermions
$ab' + b'a$	$I_{ab'}$ ($\square_a, \square_b$) fermions
$aa' + a'a$	$\frac{1}{2}(I_{aa'} - \frac{1}{2}I_{a,O})$ $\square\square$ fermions
	$\frac{1}{2}(I_{aa'} + \frac{1}{2}I_{a,O})$ $\boxminus$ fermions

D(3+2n)-branes can induce D-brane charges of lower odd dimension due to world-volume couplings. Explicitly, for one stack of N_a D-branes with wrapping number (n_a^i, m_a^i), it carries D3-, D5-, D7 and D9-brane RR charges

$$Q3_a = N_a n_a^1 n_a^2 n_a^3, \quad (Q5_i)_a = N_a m_a^i n_a^j n_a^k,$$
$$(Q7_i)_a = N_a n_a^i m_a^j m_a^k, \quad Q9_a = N_a m_a^1 m_a^2 m_a^3, \tag{3}$$

where $i \neq j \neq k$ and a permutation is implied for $(Q5_i)_a$ and $(Q7_i)_a$. Besides the D-brane and O-plane, fluxes can also contribute RR tadpole. A consistent string model requires that the RR sources satisfy the Gauss law in the compact space, *i.e*, RR tadpole must be cancelled. For D3- and D7-branes, thus we have

$$-N^{(0)} + \sum_a Q3_a - \frac{1}{2}N_{flux} = -16$$
$$-N^{(i)} + \sum_a (Q7_i)_a = -16, i \neq j \neq k,\qquad(4)$$

where $N^{(0)}$ and $N^{(i)}$ with $i = 1, 2, 3$ and 4 respectively denotes the number of filler branes, *i.e.*, D-branes which wrap along O3- and $O7_i$-planes and only contribute one of the four kinds of D3- and D7-brane charges. As for D5- and D9-brane RR tadpoles, their cancellation is automatic since D-branes and their ΩR images carry the same number charges with different signs.

Four-dimensional $N = 1$ supersymmetric vacua from flux compactification require that $1/4$ supercharges from ten-dimensional Type I T-dual be preserved in both open string and closed string sectors. On the type IIB orientifold, supersymmetric flux solutions have been discussed in [15, 24]. The configuration has RR F_3 and NSNS H_3 three-form flux turned. The supersymmetry conditions imply that the three-form $G_3 = F_3 - \tau H_3$ is a primitive , self-dual (2,1) form. Here $\tau = a + i/g_s$ is type IIB axion-dilaton coupling. The G_3 flux will contribute a D3-brane RR charge

$$N_{\text{flux}} = \frac{1}{(4\pi^2\alpha')^2} \frac{i}{2\tau_I} \int_{X_6} G_3 \wedge \overline{G}_3,\qquad(5)$$

where τ_I is the imaginary part of the complex coupling τ. Dirac quantization conditions of F_3 and H_3 on $T_6/(Z_2 \times Z_2)$ orientifold require that N_{flux} is a multiple of 64 and and BPS-like self-duality condition: $*_6 G_3 = iG_3$ ensures that its contribution to the RR charge is positive. We shall employ the following specific solution [14, 24]:

$$G_3 = \frac{8}{\sqrt{3}} e^{-\pi i/6} (d\overline{z}_1 dz_2 dz_3 + dz_1 d\overline{z}_2 dz_3 + dz_1 dz_2 d\overline{z}_3),(6)$$

where the additional factor 4 is due to the $Z_2 \times Z_2$ orbifold symmetry. The flux stabilizes the complex structure toroidal moduli at values

$$\tau_1 = \tau_2 = \tau_3 = \tau = e^{2\pi i/3},\qquad(7)$$

leading to the RR tadpole contribution in Eq(4): $N_{\text{flux}} = 192$.

For magnetized D-branes with world-volume magnetic field $F^i = \frac{n^i}{m^i \chi^i}$ in the open string sector, the four-dimensional $N = 1$ SUSY can be preserved by the orientation projection if and only if its rotation angles with respect to the orientifold-plane are an element of $SU(3)$ rotation, thus implying: $\theta_1 + \theta_2 + \theta_3 = 0$ mod 2π. Here $\chi^i = R_1^i R_2^i$, the area of the ith T^2 in α' units, is the

Kähler modulus and $\theta_i = arctan[(F^i)^{-1}]$ is the "angle" between the D-brane and the O-plane in the ith T^2.

Frameworks We choose to construct the Standard-like Models as descendants of the Pati-Salam model based on $SU(4)_C \times SU(2)_L \times SU(2)_R$. The hypercharge is thus:

$$Q_Y = Q_{I_{3R}} + \frac{Q_{B-L}}{2},\qquad(8)$$

where the non-anomalous $U(1)_{B-L}$ is obtained from the splitting of the $U(4)_C$ branes $\rightarrow U(3)_C \times U(1)_{B-L}$. Similarly, anomaly-free $U(1)_{I_{3R}}$ is part of the non-Abelian part of $U(2)_R$ or $Sp(2)_R$ gauge symmetry. Within this framework we found two classes of constructions which may yield Standard models with fluxes turned on [22]:

(i) The starting symmetry is one-family $U(4) \times Sp(2f)_L \times Sp(2f)_R$, $(f = 4)$ which can be broken down to the four-family $U(4) \times U(2)_L \times U(2)_R$ by parallel splitting the D-branes, originally positioned on the O-planes, in some two-tori directions. [Both the string theory and field theory aspects of the brane splitting in this framework is discussed in detail in [19].] In the field theory picture ("Higgsing"), the four-families $(f = 4)$ are obtained as a decomposition of the original chiral supermultiplets $(4, 8, 1)$ and $(4, 1, 8)$ into four copies of $(4, 2, 1)$ and $(4, 1, 2)$. The Higgsing, as discussed in [19], preserves D- and F-flatness and thus symmetry breaking can take place at the string scale, generating a 4D $N = 1$ supersymmetric four-family Pati-Salam model. Note furthermore, that in this case the $U(1)_L$ and $U(1)_R$ are not anomalous since they arise from the non-Abelian Sp symmetry. One expects that at least the gauge boson of $U(1)_L$ will have a mass at the electroweak scale. [This analysis can also be applied to two- $(f = 2)$ and three- $(f = 3)$ family examples. Note however, that while for $f = 2$ the Higgsing $Sp(4)_L \times Sp(4)_R \rightarrow Sp(2)_L \times Sp(2)_R$ is supersymmetric, for $f = 3$ the Higgsing $Sp(6)_L \times Sp(6)_R \rightarrow Sp(2)_L \times Sp(2)_R$ breaks supersymmetry [19].]

(ii) The starting symmetry is Pati-Salam-like $U(4)_C \times Sp(2)_L \times Sp(2)_R$. Recently, in [17] the constructions of this type were explored to obtain the first examples of semi-realistic Standard Model flux compactifications.

The gauge symmetry in the observable sector is $SU(4) \times SU(2)_L \times SU(2)_R$, with the subsequent symmetry breaking chain [19]:

$$\begin{aligned} &SU(4) \times SU(2)_L \times SU(2)_R \\ \rightarrow\ &SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_{B-L} \\ \rightarrow\ &SU(3)_C \times SU(2)_L \times U(1)_Y.\end{aligned}\qquad(9)$$

Here the first step can be achieved by splitting the ath stack of D-branes at string scale and the second one by giving VEVs to the scalar component of right-handed neutrino superfield at TeV scale. Therefore at the electroweak scale one would only have the minimal supersymmetric Standard Model content.

Within the above frameworks classes four- and three-family supersymmetric Standard Models are presented in

TABLE II: D-brane configurations and intersection numbers for the four-family supersymmetric Standard-like Models with three-units of quantized flux. Here, $r = 3, 4$, χ_i is the Kähler modulus for the ith two-torus, and β_j^g is the beta function for the Sp group from the jth stack of branes. These models have discrete global anomaly.

$[U(4)_C \times Sp(8)_L \times Sp(8)_R]_o \times [U(1) \times Sp(32r-88) \times Sp(8-2r)]_h$										
j	N	$(n^1,m^1)(n^2,m^2)(n^3,m^3)$	$n_{\square}$	$n_{\square}$	b	c	d	d'	1	2
a	8	$(1,0)(1,1)(1,-1)$	0	0	1	-1	15	-15	0	0
b	8	$(0,1)(1,0)(0,-1)$	0	0	-	0	4r	-4r	0	0
c	8	$(0,1)(0,-1)(1,0)$	0	0	-	-	4r	-4r	0	0
d	2	$(-r,-1)(4,1)(4,1)$	72r	56r	-	-	-	-	1	-16
1	32r-88	$(1,0)(1,0)(1,0)$	$\chi_1 = 8r\chi_2/(\chi_2^2 - 16), \chi_2 = \chi_3$							
2	8-2r	$(1,0)(0,-1)(0,1)$	$\beta_1^g = -11/2$							

Table II and Table III, *i.e.*, those models have three-units of quantized flux. However, the branes with the $U(1)$ symmetry have an odd number of intersections with the Sp branes, thus introducing an odd number of fundamental representations of Sp, *i.e.* the models suffer from the discrete global anomaly [20]. The conditions for the absence of discrete global anomalies can be derived from the K-theory [25] and have been given for the $Z_2 \times Z_2$ orientifolds in [21]:

$$\sum N_a m_a^1 m_a^2 m_a^3 = 4Z, \ \sum N_a n_a^i m_a^j m_a^k = 4Z,$$
$$\sum N_a m_a^i n_a^j n_a^k = 4Z, \ \sum N_a n_a^1 n_a^2 n_a^3 = 4Z, \quad (10)$$

where Z is an integer. These conditions turn out to be extremely constraining and within the above framework no anomaly-free four- or three-family models with three units of quantized flux exist. Thus, explicit constructions of semi-realistic models with supersymmetric fluxes remain elusive.

Classification We now turn to the classification of the supersymmetric D-brane constructions with $Sp(2f)_L \times Sp(2f)_R$ electroweak sector (framework (i)) with the maximal number of flux units turned on [Within framework (ii) a related analysis was done in [21].] In the following $n_f = N_{flux}/64$, and $(n_f)_{max}$ is the largest allowed unit of the quantized flux:

(1) Four-families ($f = 4$): $(n_f)_{max} = 1$. We display a representative example in Table IV with the $U(2)$ symmetry in the hidden sector. We also found another model with hidden sector symmetry $U(1) \times U(1)$ and respective brane configurations $(-1,-1)(3,1)(2,1)$ and $(-3,-1)(1,1)(2,1)$. [Within framework (ii) there are no models with $n_f \neq 0$.]

(2) Three-families ($f = 3$): $(n_f)_{max} = 1$. The solution possesses the hidden sector gauge symmetry with unitary gauge sector $U(1) \times U(1)$ and the respective brane configurations $(-2,-1)(2,1)(3,1)$ and $(-2,-1)(3,1)(2,1)$. However, since the Higgsing of $Sp(6)_L \times Sp(6)_R \rightarrow Sp(2)_L \times Sp(2)_R$ breaks supersymmetry [19] these D-

brane models are not supersymmetric. [Within framework (ii), the solution found in [17] is the only possible one.]

(3) Two-families ($f = 2$): $(n_f)_{max} = 2$. In Table IV we present a model with the $U(2)$ symmetry in the hidden sector. We also found models with $U(1) \times U(1)$ in the hidden sector. [Witnin framework (ii) the only example is given in [17].]

(4) One-family ($f = 1$): $(n_f)_{max} = 3$. In this case frameworks (i) and (ii) are equivalent. The only example with $(n_f)_{max} = 3$ was obtained in [17]. For the case with one tilted two-torus, there are models with $n_f = 2$ and $U(2)$ or $U(1) \times U(1)$ gauge symmetry in the hidden sector.

Moduli Stabilization These models typically contain a "hidden sector", associated with D-branes, parallel with the O-planes ("filler" branes), whose gauge group factors have negative beta functions. If such a gauge gauge factor were associated with a stack of D7$_i$-branes, the infrared non-perturbative gauge dynamics could generate a superpotential of the form (see, e.g., [26]):

$$W_{eff} = \frac{\beta_i \Lambda^3}{32e\pi^2} \exp\left(\frac{8\pi^2}{\beta_i} f_W(T_i)\right) + W_o, \quad (11)$$

where the gauge function $f_W(T_i) = n_i^1 m_j^2 m_k^3 T_i$ ($i \neq j \neq k \neq i$), T_i is the toroidal Kähler modulus for the i-th two-torus, β_i is the beta function, Λ is the cutoff string scale and W_o is a contribution from the fluxes [28] which fixes the dilaton and complex structure moduli. [Due to the flux back-reaction the open string sector moduli are expected to get a mass [14]; in this case the supersymmetry conditions fix the rest of toroidal Kähler moduli (say, Re$T_{j,k} \sim \chi_{j,k}$ in terms of T_i).] Models desplayed in Table IV possess only the hidden sector D3-branes with confining gauge symmetry. However, a generalization [27] of the present constructions, does provide Standard-like flux models with such confining D7$_i$-branes. Note, that for supersymmetric flux ($n_f = 3$) $W_o = 0$, and for the non-supersymmetric ones ($n_f = 1, 2$) $W_o \neq 0$. In the latter case the resulting W_{eff}, along with the Kähler potential for the volume modulus, determine the supergravity potential whose ground state would fix also the remaining toroidal Kähler modulus [28]. However, for the models under consideration $W_o = \mathcal{O}(M_P^3)$ and thus the volume modulus $f_W = \mathcal{O}(1)$. A mechanism to turn on a small value for W_o remains an open problem.

TABLE III: D-brane configurations and intersection numbers for three- and four-family supersymmetric Standard-like Models with three units $n_f = 3$ of the quantized flux. f is the family number, and $2 \leq r \leq 4$ for $f = 3$ and $3 \leq r \leq 4$ for $f = 4$. χ_i is the Kähler modulus for the ith two-torus, and β_j^g is the beta function for the Sp group from the jth stack of branes. These models have discrete global anomaly.

$[U(4)_C \times Sp(2)_L \times Sp(2)_R]_o \times [U(1) \times Sp(98r - 8f^2 - 80) \times Sp(8 - 2r)]_h$										
j	N	$(n^1,m^1)(n^2,m^2)(n^3,m^3)$	$n_{\square\square}$	$n_{\square}$	b	c	d	d'	1	2
a	8	$(1,0)(f,1)(f,-1)$	0	0	f	-f	$49 - f^2$	$f^2 - 49$	0	0
b	2	$(0,1)(1,0)(0,-1)$	0	0	-	0	$7r$	$-7r$	0	0
c	2	$(0,1)(0,-1)(1,0)$	0	0	-	-	$7r$	$-7r$	0	0
d	2	$(-r,-1)(7,1)(7,1)$	210r+33	182r-33	-	-	-	-	1	-49
1	$98r - 8f^2 - 80$	$(1,0)(1,0)(1,0)$	$\chi_1 = 14r\chi_2/(\chi_2^2 - 49), \chi_2 = \chi_3$							
2	$8 - 2r$	$(1,0)(0,-1)(0,1)$	$\beta_1^g = -11/2$							

TABLE IV: D-brane configurations and intersection numbers for the consistent f-family Standard-like Models with n_f-units of quantized flux. χ_i is the Kähler modulus for the ith two-torus, β_j^g is the beta function for the Sp group from the jth stack of branes. The allowed models have $f = 2, 4$ with $(n_f)_{max} = 2, 1$, respectively.

$[U(4)_C \times Sp(2f)_L \times Sp(2f)_R]_o \times [U(2) \times Sp(8(4 - \frac{f}{2})^2 + 16 - 32n_f)]_h$									
j	N	$(n^1,m^1)(n^2,m^2)(n^3,m^3)$	$n_{\square\square}$	$n_{\square}$	b	c	d	d'	1
a	8	$(1,0)(1,1)(1,-1)$	0	0	1	-1	$(4-\frac{f}{2})^2 - 1$	$-(4-\frac{f}{2})^2 + 1$	0
b	8	$(0,1)(1,0)(0,-1)$	0	0	-	0	$2(4-\frac{f}{2})$	$-2(4-\frac{f}{2})$	0
c	8	$(0,1)(0,-1)(1,0)$	0	0	-	-	$2(4-\frac{f}{2})$	$-2(4-\frac{f}{2})$	0
d	4	$(-2,-1)(4-\frac{f}{2},1)(4-\frac{f}{2},1)$	$\chi_1 = (16-2f)\chi_3/(\chi_3^2 - (4-\frac{f}{2})^2)$						
1	$8(4-\frac{f}{2})^2 + 16 - 32n_f$	$(1,0)(1,0)(1,0)$	$\chi_2 = \chi_3, \beta_1^g = -5$						

* Electronic address: cvetic@cvetic.hep.upenn.edu; Electronic address: liutao@physics.upenn.edu

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